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ILLUMINATION LEVELS AND COMFORT CONDITIONS AS APPLIED TO THE LIGHTING, HEATING, AND VENTILATING PROBLEM

By F. C. SMITH, M.Inst. Gas E. *(Member).*

(Paper read on Tuesday, March 1st, 1938.)

Introduction.

Few amenities are of greater importance than effective heating and lighting. The fact that improper heating, inadequate or badly arranged ventilation are detrimental to health is a matter of experience and beyond dispute. It is not surprising, therefore, that intensive study has been made of these problems during the past few years. This work has resulted in a more complete understanding of the physiological reactions of the average subject to the heating and ventilation conditions obtaining in an environment. It is now possible to define environment conditions in terms of well understood physical measurements and, although the limitations of these measurements are appreciated, to compute with reasonable accuracy how the subject will react to the conditions.

In a meeting before this Society it is unnecessary to stress the importance of good lighting. To the illuminating engineer it is axiomatic that the lighting must be adequate for the situation and allow of the ready and continuous performance of any given task without involving avoidable eye strain or unnecessary fatigue.

The careful lighting of moving machinery, corridors, stairs, entrances, lift shafts, etc., is essential to safety. Throughout the paper the author has quoted freely from published work which, although it may be familiar to either the heating or the illuminating engineer, is probably not commonly known to both.

Relationship between Heating and Ventilating, and Lighting.

In considering the subject matter for this paper the author has been impressed with the many points of contact in the science and technique of these subjects. It may be helpful if the more important of these are stated at the outset, since it is these considerations which justify the joint meeting between the two organisations concerned.

1. Both techniques are concerned with the physiological response and, to a greater or lesser extent, with the psychological reaction of the subject to external stimuli.
2. Both interests seek to establish a physical index to the subjective response of the individual.
3. Although the heating and ventilating engineer is not concerned solely with the subjective response to radiation, it is, nevertheless true, that he has a great deal to do with thermal radiation. Both heating and ventilating engineers are deeply concerned with the same physical phenomenon, the only difference being that different bands of wave-lengths are of greater importance to each. It is common practice for the lighting engineer to use either polar or iso-candle distribution diagrams in the calculations involved in illuminating engineering. The heating engineer is now using similar diagrams in his own work. (See Figs. 7 and 8.)
4. The production of light even by the most modern methods is a comparatively inefficient process and in consequence heat which is the major consideration of the heating engineer is the "by-product" of the production of light. It will be shown that at high levels of illumination, especially with low "utilisation factors," the amount of heat liberated in the production of light is great and may have a considerable bearing upon heating requirements. In particular it is the aim of this paper to bring the requirements of both amenities into focus so that the most desirable result from both points of view may be achieved.
5. The problem for both heating and lighting engineers is complicated by the fact that the subject may become involuntarily adapted to conditions which may be prejudicial.

In order to get a better understanding of the problem, it is of interest to consider the points mentioned in greater detail.

The object of any heating and ventilating system is to establish a set of conditions which the "average" individual will regard as comfortable, and which will be healthy.

The term comfortable is indefinite, and it is, therefore, pertinent to seek a more precise meaning than is conveyed by the ordinary use of the term, but any attempt at such a definition must still, in the ultimate, be based upon the judgment of the subject. This judgment will in turn be determined by the physiological response of the subject to the surrounding conditions.

Clearly, as in matters affecting visual response, the reactions of an individual are not of necessity representative of the response of the "average" subject. In consequence, it has been found desirable to study the reactions of a large number of subjects to conditions which in their judgment represent differing orders of comfort. Assuming a reliable index to environment conditions to be available it should be possible to define "degrees of comfort" in terms

of a physical index, and thus give some degree of precision to the term comfort.

An investigation of this kind has been undertaken by Bedford (1), who adopted the method of statistical correlation to determine the degree of association between the comfort votes of a number of subjects and the readings obtained from several types of instrument used as an index to environment condition.

In this paper the subject of comfort conditions is dealt with in broad outline only. In passing, however, it may be helpful to those unfamiliar with the subject to indicate that the acceptable conditions are known to depend in some measure upon the degree of physical exertion demanded for the performance of the work upon which the individual is engaged.

In addition, certain industrial processes result in or demand for successful operation, air conditions, etc., which are abnormal and detrimental to comfort unless the heating and ventilating system can provide suitable compensations.

Factors Associated With Artificial Heating Which Influence Health and Comfort.

The following statement occurs in a report (2) issued in December, 1936, by the Royal College of Physicians:—

"The factors associated with artificial heating which influence comfort and health are of three main types, physical, chemical, and bacteriological. Provided the air is pure within reasonable limits, ideal conditions of comfort are determined by the simultaneous operation of a number of physical factors which exert an influence on the heat interchange between the body and its environment.

"The human body even when resting is continuously producing heat. In the case of a sedentary individual the heat produced has been estimated at 350-450 British Thermal Units per hour, the average figure being 400 B.Th.U. This heat must be got rid of by the body, and the rate and manner of its loss largely determines comfort sensations. In still air, and at a relative humidity of 50 per cent., a normally clothed individual, sitting in a room in which the temperature of the air and of the surroundings is approximately 60° F., loses these 400 B.Th.U's of heat approximately as follows: 45 per cent. by radiation, 31 per cent. by convection, and 24 per cent. by evaporation of moisture from the lungs and skin."

This statement is quoted at length since it is an authoritative summary of the most general conclusions to be derived from recent investigations and serves to focus attention upon the two principal factors affecting human comfort under conditions of artificial heating.

It is clear that comfort is dependent upon:—

(1) The rate of heat interchange between the clothed human body and its environment. This ensures the necessary heat loss.

(2) The manner in which heat is lost from the body. In order to be comfortable it should not be necessary for emergency reactions, such as sweating, to take place.

The factors which will influence this rate of heat interchange are:—

(1) The mean surface temperature of the clothed body.

(2) Air temperature.

(3) Air movement.

(4) Temperature of walls and other objects in the environment.

(5) Humidity.

(6) Bodily exertion, the generated heat being dissipated mainly by evaporation.

(7) Actual clothing worn.

The Influence of the Various Factors on Comfort.

There is nothing mysterious about the factors influencing the rate of heat loss from the body. They are similar to those affecting heat loss from any other body with a surface temperature controlled constant within narrow limits, with this exception, that only in certain cases in the general problem of heat loss is it necessary to consider the heat loss by evaporation.

In general, the losses by convection and radiation at a surface losing heat freely are governed by (1) the temperature difference between the hot body and its surroundings, (2) the temperature and rate of movement of the air passing over the surface, (3) the emissivity of any surface taking part in the radiation exchanges, and (4) the shape of the object losing heat.

It is more difficult, however, to relate each factor with subjective response.

Bedford (7), from consideration of his observations, has suggested the following relationships:—

$$S = 11.6 - 0.0556\,t_a - 0.0538\,t_w - 0.0372f + 0.00144\sqrt{v}(100 - t_a) \quad \text{(i)}$$

where t_a = air temperature in °F.

t_w = mean temperature of surrounding °F.

f = partial pressure of water vapour present in air in mm. of mercury.

v = air velocity in ft. per minute.

and S is the comfort vote according to the following numerical scale.

when S = 1, the conditions are much too warm.

S = 2, „ „ „ too warm.

S = 3, „ „ „ comfortably warm.

S = 4, „ „ „ comfortable.

S = 5, „ „ „ comfortably cool.

S = 6, „ „ „ too cool.

S = 7, „ „ „ much too cool.

The following instruments have been used either

as a direct indication of, or as aids to, computing the physical conditions prevailing in an environment:—

(1) Liquid in glass thermometers.
(2) Hygrometers (wet and dry bulb instruments, etc.).
(3) Anemometers and similar instruments for measuring air velocities.
(4) Eupatheoscope.
(5) Globe thermometer.
(6) Kata thermometer.

Liquid in Glass Thermometers.

Provided such simple precautions as shielding the bulb from radiation, etc., are observed a thermometer indicates air temperature, and is, therefore, a direct measure of one of the factors influencing comfort.

If it is assumed that:—

(1) Comfort is independent of humidity,
(2) Walls and other objects in the environment are approximately air temperature,
(3) The velocity of air movement does not exceed a given minimum,

then the readings obtained could be related to subjective response, and become a useful index to comfort. It is agreed also that for an established set of conditions the air temperature can be an exceedingly useful indication, especially when interpreted by a skilled person.

In practice, however, the conditions referred to above seldom obtain, and this fact must impose limitations upon the usefulness of thermometer readings.

Wet and Dry Bulb Thermometers and Anemometers.

These instruments afford information in regard to two factors, viz., air temperature and humidity, and as such are useful, but have the limitation of ignoring the radiation component. In a similar way anemometers give the required information about one factor only, i.e., the velocity of air movement.

Since comfort conditions are dependent upon several factors, the limitations of the usual scales of temperature are apparent, and in consequence other scales have been proposed and adopted. These scales of "temperature" and the instruments used for their measurement in reality compound into a single reading on the special scale, the effect of a selected number of factors influencing comfort conditions.

The more important of these scales are:—

(1) Equivalent temperature scale.
(2) Equivalent warmth scale.
(3) Effective temperature scale.

Equivalent Temperature.

Before the fact that environmental conditions had a marked effect upon the mean temperature of the clothed body was fully taken into account, the following definition of equivalent temperature was applicable:—

"The equivalent temperature of an environment may be defined as that temperature of a uniform enclosure in which, in still air, a black body of sufficient size at 75°F. would lose heat at the same rate as in the environment."

The instrument for measuring equivalent temperature is the eupatheoscope. This instrument was designed by Dufton, and consists of a hollow blackened copper cylinder of 7½ in. diameter and 22 in. high. The surface temperature in the original instrument is maintained constant by a thermostatically controlled heating element inside the instrument. The actual change in the rate of heat loss from the eupatheoscope and hence the recorded equivalent temperature is solely dependent upon conditions external to the instrument. If excessive heat loss by evaporation consequent upon heavy bodily exertion or abnormal temperature conditions be ignored then there is a close similarity between the rate of heat loss from the eupatheoscope and the clothed human body.

It has been established that for ordinary sedentary occupation an equivalent temperature of 65°F. (corresponding to a rate of heat loss from the instrument of 17.5 B.Th.U. per sq. ft. per hour) represents a set of physical conditions which ensure the optimum rate of heat interchange between the human body and its environment.

The instrument has now been modified by Dufton so that in the new type the surface temperature is controlled to a value almost identical with the mean temperature of a clothed human body in the environment.

The modified definition of equivalent temperature as proposed by Bedford is as follows:—

"The equivalent temperature of an environment is that temperature of a uniform enclosure in which, in still air, a black body of sufficient size would lose heat at the same rate as in the environment, the surface temperature of the body being one-third of the way between the temperature of the enclosure and 100°F.

This new instrument has now been accepted as the standard instrument for the measurement of equivalent temperature by the Inter-Departmental Committee on Heating and Ventilation Research.

The eupatheoscope compounds the effects of air temperature, heat interchange by radiation between the instrument and the surroundings and heat loss consequent upon air movement over the instrument, but ignores entirely the effect of humidity.

At this point it is convenient to call attention to an important fact in comfort measurements.

It is clear, for instance, that an equivalent temperature at 65°F. would be attained if the air and walls, etc., of an environment were at 65° F. with still air conditions. On the other hand the same equivalent temperature might be secured with air at a lower temperature, and where the walls, etc., contribute the necessary radiation component. Although the conditions postulated result in the same equivalent temperature there is evidence that the comfort conditions are not identical.

In some experiments carried out by Fishenden and Willgress ([20]) the air temperature was brought to any desired level and subjects set at various distances from a source of radiation. The comfort impressions

of the subject were recorded for each position and air temperature. The results are plotted on Fig. 1, in which the mean horizontal component of radiation over the position of the observer is plotted against air temperature for (1) comfort, (2) " upper limit slightly too warm," and (3) " lower limits slightly too cold."

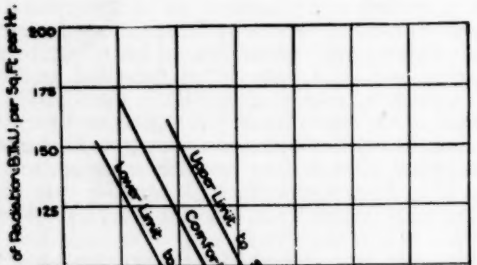

Fig. 1.

" It was found, as would be expected, that for every degree which the temperature of the air and surroundings was reduced below the comfort value of 65°F., an increased intensity of the mean radiation in the position of the observer was demanded for comfort. That is to say, the subjects were warm enough at 65°F. without extra radiation; at 60°F. a mean horizontal component of about 30 B.Th.U. per square foot per hour produced warmth; at 55°F., 75 B.Th.U.; at 50°F. 120 B.Th.U.; and at 45°F. 170 B.Th.U. per square foot per hour. They were very slightly chilly in air at 62°F. without extra radiation; at 60°F. with mean horizontal radiation 10 B.Th.U. per square foot per hour; at 55°F. with 40 B.Th.U.; at 50°F. with 85 B.Th.U., and at 45°F. with 133°B.Th.U. per square foot per hour. Whilst they were slightly too warm in air at 68°F. without extra radiation; at 60°F. with 57 B.Th.U. per square foot per hour; at 55°F. with 103 B.Th.U.; at 50°F. with 153 B.Th.U., and at 45°F. with 208 B.Th.U. per square foot per hour.

" The most comfortable conditions, corresponded with an air temperature of about 55°F. in conjunction with the requisite intensity of radiation for warmth. When the air temperatures exceeded 58°F. or 59°F. a slight feeling of mental lassitude was produced, although radiation was still required to maintain warmth without physical exertion."

It is clear if the optimum equivalent temperature is obtained the comfort conditions are optimum for the particular system of heating employed. It may be, however, that for another system of heating the same equivalent temperature would correspond to improved or inferior comfort conditions.

Scale of Equivalent Warmth.

Whilst it is true in this country that humidity has only a very secondary effect upon comfort, under other conditions it becomes of greater moment.

It is clearly desirable that a scale should be available which takes into account all the factors.

On the basis of equation (i) Bedford has constructed a provisional scale of equivalent warmth.

If the appropriate values for the air temperature, mean temperature of surroundings, partial pressure of water vapour present, and air velocity are known the equivalent warmth is readily computed from a nomogram proposed by Bedford.

As illustrative of the meaning and application of this scale consider an example quoted by Bedford.

The air temperature in an enclosure is 65° F., the vapour pressure 10 mm. of mercury, the air velocity 25 ft. per minute, and the mean temperature of the surroundings 70° F., it can be calculated that the equivalent warmth of this enclosure is 63.5° F.

Observations appear to suggest that the best condition for comfort under sedentary conditions is an equivalent warmth of 61° F.

Effective Temperature Scale.

This is also an experimentally determined scale, which is a measure of, or index to, a person's feeling of warmth in all conditions of temperature and humidity.

Experimental evidence suggests that for persons wearing normal clothes, over 90 per cent. of persons are comfortable at an effective temperature of 64° F. in still air. In consequence, 64° F. effective temperature has been termed the comfort line.

The range of temperatures between 62°- 69° effective temperature is known as the comfort zone. In practice, the air is seldom, if ever, still and, as air movement has an important bearing upon comfort, this factor has been taken into account in this scale.

Tables are available giving the corresponding effective temperature for various wet and dry bulb conditions, and taking into account the velocity of air movement. The limitation of this scale is that it makes no allowance for heat exchange by radiation between the body and surrounding objects, etc.

The Globe Thermometer.

If two similar mercury in glass thermometers be hung side by side in an environment in still air with walls at a different temperature from that of the air of the environment, and if the bulb of one instrument be blackened whilst the other be screened from radiation, then it is clear that the readings recorded will differ from each other. The difference may be increased if thermometers with larger bulbs are used. For any given size of thermometer bulb the actual difference in reading will depend upon the radiation component absorbed by the blackened surface. Since comfort conditions are related to both the air temperature and the radiant energy interchange be-

tween the body and the environment, Vernon has proposed a special type of blackened bulb thermometer known as the globe thermometer. According to Vernon ([8]) a thermometer with a bulb having a diameter of from 6 to 9 inches is necessary in order to obtain a radiation effect comparable to that experienced by the human body.

Such a thermometer may be constructed by blackening an ordinary cistern ball valve and arranging a mercury in glass thermometer so that the bulb is at the centre of the ball.

If such a thermometer be used in a room with walls at a higher temperature than the air, the difference in temperature between the shielded mercury in glass thermometer and the globe thermometer is termed by Vernon the effectual radiation temperature.

The value of the globe thermometer must depend upon its ability to give an approximately correct measure of radiation and convection in so far as these affect human comfort. It has the merit of simplicity and is an inexpensive instrument.

The following table, abstracted from results obtained by Vernon, is instructive, since both observers were comfortable with the three differing types of heating, and with air temperatures varying over a range of from 49.3°F. to 61.7°F., provided the sum of the effectual radiation temperature and the air temperature as indicated by the globe thermometer had a value of approximately 62-63°.

TABLE I

Source of radiant heat.	Mean air temperature °F.	Effectual radiation temperature °F.	Radiation — convection temperature experienced by subjects °F.
Gas Fire	49.3	12.8	62.1
„ „	53.8	7.7	61.5
„ „	57.2	4.6	61.8
Stove	56.5	6.3	62.8
„	59.0	2.4	61.4
„	61.2	0.4	61.6
Ceiling Panels ...	60.8	1.6	62.4
„ „ ...	61.7	1.2	62.9

During the above observations the relative humidity was fairly steady, ranging only from 55 to 71 per cent. Within these limits, however, the effect of changing humidity would have little effect upon the general conclusion.

Incidentally it has been shown by Bedford and Warner that the mean temperature of the surroundings can be determined from readings of the globe thermometer if the temperature and velocity of the air are known, a point which will be referred to later in the paper.

Kata Thermometers.

It has been convenient to refer to these instruments somewhat late in this paper, although they were described as far back at 1916 by Hill, Griffith and Flack ([9]). An important paper on the uses of the Kata thermometer was published by Angus in 1936 ([10]). He states:—

> "As first introduced the Kata thermometer was intended to indicate and measure a wide range of atmosphere conditions in relation to health and comfort; having a sufficiently open scale to enable out-door meteorological conditions to be measured on the one hand and the environmental conditions in various inhabited buildings on the other."

Sir Leonard Hill has described the Kata as an instrument for the measurement of its own rate of cooling when its temperature approximates to that of the human body. In consequence, like all other instruments for the calculation of comfort conditions, the readings obtained have to be correlated to the physiological response of the average individual to the prevailing conditions.

In its simple form the instrument consists of an alcohol in glass thermometer with a bulb of about 1½ in. in length and ¾ in. diameter. On the stem the Kata thermometer has two calibration marks only at 95° F. and 100° F., the mean temperature 97.5° F. being the approximate temperature of the bare parts of the human skin.

In use the instrument is placed in hot water, and its alcohol thread allowed to move up the capillary into a reservoir provided at the top of the scale. The Kata is withdrawn from the water, wiped, and suspended freely in the environment, and the time noted for the thread to fall from the 100° to the 95° mark. On the stem of each Kata is engraved the factor for the particular instrument. If this factor be divided by the time in seconds for the thread to fall between the calibration marks the result obtained is the cooling power of the air on the bulb in millicalories per sq. cm. per second.

It has been suggested by Hill that under ordinary circumstances a value of approximately 6 for this figure indicates a desirable condition.

Several forms of this instrument are available which enable the measurement of the following distinctive features of environmental condition as they affect the subject. These have been summarised by Angus ([10]) as follows:—

(1) Cooling Power (wet or dry). A scale of comfort, though like others open to question.
(2) Evaporation Power:—Of air in respect of its saturation deficiency at body temperature and air movement over a warm wet surface.
(3) Air Velocity. At both fairly high and quite low speeds.
(4) Mean Radiant Temperature.
(5) Equivalent Temperature.

There can be little doubt that in the hands of an experienced worker the dry Kata can be a very useful instrument provided its limitations are known and guarded against.

The Air Thermometer, Globe Thermometer, and Silvered Kata Thermometer Used Conjointly.

The eupatheoscope has certain severe practical limitations. In the first place it may be necessary to determine almost simultaneously the prevailing con-

ditions at various parts of a large hall or factory: the expense of the instrument makes this prohibitive. In addition, the instrument is somewhat delicate and inconvenient to move about.

Bedford (11) has developed a chart whereby the equivalent temperature can be computed if the temperature and velocity of the air are known together with the mean temperature of the surroundings.

The air temperature can be measured directly by a mercury in glass thermometer if the bulb is shielded from radiation effects by aluminium foil; the silvered Kata may be adopted with confidence to measure air velocity; and from the globe thermometer may be computed the mean temperature of the surroundings.

Thus, these three relatively expensive instruments may be used to determine equivalent temperature, and this may in turn be related to the scale of equivalent warmth if wet and dry bulb readings are recorded.

A further simple instrument, known as the eupatheometer, is available. This instrument consists of a silvered and blackened Kata thermometer mounted together. An ingenious device eliminates the somewhat tedious calculations otherwise necessay. To sum up: Equivalent temperature may be measured directly by the eupathescope, or calculated from measurements of the temperature and velocity of the air and the mean temperature of the surroundings as computed from the readings of the globe thermometer. If, in addition, the vapour pressure is known the equivalent warmth may be computed by using a nomogram (12).

Air Change as Distinct from Air Movement.

So far no distinction has been made between the effects consequent upon the movement of air already present in an environment, and that brought about by air changes The value of reasonable air movement is not disputed, and it is agreed that the admission of clean fresh air is essential to health.

To quote the Medical Report previously referred to: (2) "The ventilation of rooms needs to be such that, while health is safeguarded, comfortable conditions of warmth may be readily and economically established and maintained under conditions of normal occupation."

There is a growing tendency to believe that chimney flues are not essential in living rooms, etc., and the trend, in modern buildings, is to rely upon air bricks. It is very questionable if such arrangements are satisfactory, especially having regard to the materials now used and the modern methods of construction.

This matter is at the present time under active consideration by the Health Organisation of the League of Nations.

The standards of ventilation adopted up to the present have been based largely upon the volume of air necessary to the removal of body odours.

Dr. de Chaumont (13) concluded that so long as the carbon dioxide due to respiration did not exceed 2 parts per 10,000, the air of the room seemed fresh and did not differ sensibly from the outside air. The average individual produces about 0.6 cu. ft. of CO_2 per hour. On the above basis this represents a requirement of 3,000 cu. ft. per hour per person. Body odours are just apparent when the CO_2 due to respiration reaches about 4 parts per 10,000. This concentration is equivalent to a requirement of 1,500 cu. ft. per person per hour.

Further work has been done by American workers (14), and the following table has been abstracted from the results obtained:—

TABLE II.

Minimum Values of Outdoor Air Requirements.

Type of Occupant.	Air Space Per Person. Cu.ft.		Fresh Air Supply Required. Cu.ft.per minute per person.
Sedentary adults of average socio-economic status	100	.....	25
	200	.....	16
	300	.....	12
	500	.....	7
Labourers	200	.....	23
School children of average class	100	.....	29
	200	.....	21
	300	.....	17
	500	.....	11
School children of poor class	200	.....	38
School children of better class	200	.....	18

The table serves to illustrate the fact that the intensity of odour varies with the number of occupants as well as with the fresh air supply per person. These workers concluded that for persons of average cleanliness 1,000 to 1,200 cu. ft. per hour per person will give satisfactory results.

These considerations emphasize the need of adequate air change whatever the source of heating may be.

Illumination and Seeing.

The lighting engineer could, with good reason, criticise the title of this paper if it be held to convey that lighting requirements are satisfied by the provision of a given number of lumens resulting in the obtaining of a prescribed "level" of illumination.

Since the name of this Society is not "the Foot-Candle Society" it is clear that no such suggestion is implied.

Illuminating engineers must take into account, so far as present knowledge permits, all the requirements and reactions of the sight organs, and control the external stimuli producing these reactions in such a way as to secure easy vision and absence of any avoidable visual fatigue.

At present it is not possible to group together the many factors external to the subject, and propose a "scale of equivalent vision" which would be similar in application in its own sphere to the scale of equivalent warmth to which reference has been made. It would be a great advance if some instrument were

available with a scale of numbers which would relate the subject's visual response to the net effect of the factors influencing vision. The success of any such instrument would pre-suppose that its use in no way changed the adaptation, etc., of the eyes—a difficult condition to satisfy. Those familiar with the subject will be aware of the work that has been done in this country and abroad in an attempt to relate visual response with external conditions.

It is a relatively simple matter to investigate the effect of varying any one factor at the threshold of vision, but much more difficult to assess the effect of changes at levels removed from the threshold. These latter conditions, however, are those that are of the greatest importance in practice. The matter is still further complicated since the effect of several factors operating simultaneously has to be considered.

Among the more important of the factors are:—

(a) Field brightness.
(b) Brightness contrast.
(c) Object size.
(d) Time of presentation.
(e) Glare.
(f) Colour.

Here again this matter has been treated only in the broadest outline, but it will suffice for the purpose of this paper if a few typical relationships are considered.

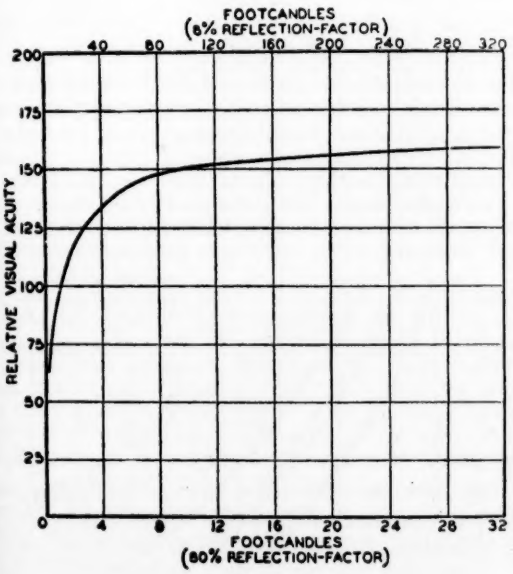

Fig. 2.

In Fig 2 ([15]) relative visual acuity has been plotted against illumination for a black object viewed against "white" and dark grey backgrounds respectively.

If this curve be examined it is clear that visual acuity increases rapidly up to an illumination of 8 foot-candles when the black object is seen against a white surface of 80 per cent. reflection factor.

Under these conditions, above an illumination of 8 foot-candles, visual acuity increases very slowly. On the other hand, if the background has a reflection factor of only 8 per cent. visual acuity is considerably facilitated up to 80 foot-candles, but, as before, above this critical value improvement is small, even if the illumination be increased fourfold.

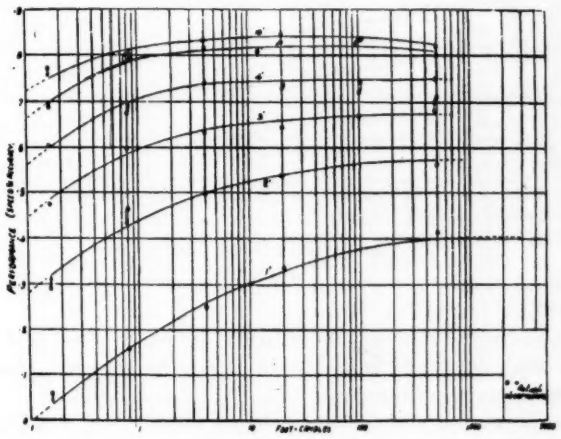

Fig. 3.

Fig. 3, due to Weston ([16]), shows the relation between performance (as judged by speed and accuracy) and illumination. Each curve refers to a particular object size, the object size ranging from 1 to 10 minutes of arc subtended at the eye.

It is important to note that when the object size is small the curves do not flatten until the illumination reaches a high value (above 100 foot-candles), but the improvement of performance from 20-30 foot-candles upwards is relatively small, and in suitable cases the use of special spectacles rather than higher illumination values would be a better means of obtaining further improvement, or additional eye comfort, for the performance of these exacting tasks. For object sizes of 10 minutes little improvement is secured above a value of something like 6 foot-candles. On the other hand, Weston has shown that the performance for fine work falls considerably below the maximum possible if the illumination is only 3-5 foot-candles, and remarks that these values are frequently found in factories.

In Fig. 4 ([17]) will be found plotted the relationships existing between size of object, contrast and brightness over wide ranges for each variable.

In these observations exposure time was kept constant. The conditions plotted are for border-line vision, and the relationships shown were established by averaging the results obtained from nine subjects. It should be particularly noted that the brightness scale is logarithmic.

A further point of interest that emerges from these curves is that even with a field brightness of 100 millilamberts and the maximum possible contrast, it

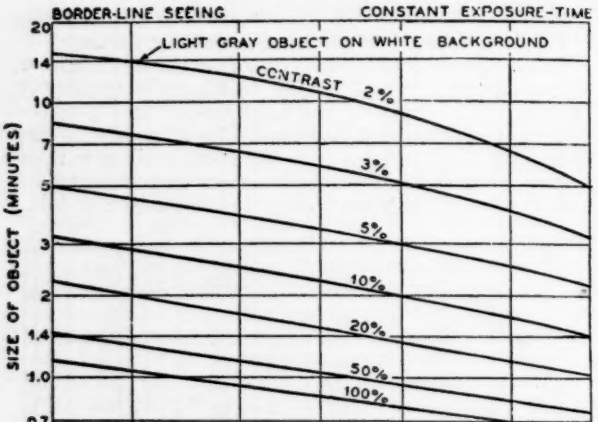

Fig. 4.

was impossible for the subject to resolve an object subtending an angle with the eye of less than approx. 0.6 minutes.

This supports Weston's view that below a given object size visual help is best provided by lenses rather than by illumination. From the economic point of view this solution is clearly advantageous, and it will be shown later, if these high values are to be achieved over other than relatively small areas, considerable difficulty will be experienced in securing comfort conditions.

A further aspect of the subject is revealed in Fig. 5 ([18]).

This curve shows the relationship between the necessary time of exposure and the brightness for a given test object to insure (A) a 50 per cent. certainty, (B) an 80 per cent. certainty, and (C) a certainty of slightly less than 100 per cent. of seeing. The object size was kept constant in these experiments. The curve was obtained by measuring the threshold time, which is the least time a stimulus must act to enable the subject to respond and make the necessary muscular reactions demanded by the task.

This threshold time is influenced by the conditions surrounding the eyes, the dimensions of the test object, the available contrast, and the general brightness level. The curve shown is only one of a family of such curves obtained by Luckeish and Moss, but serves to indicate the general form of the relationship.

Once again the logarithmic nature of the relationship is apparent. In the case of the curve C it is necessary to increase the brightness by approximately 100 times to diminish the time to 1-10th.

It is apparent that these relationships will be greatly affected if the source of light has a natural frequency, i.e., flicker.

Glare.

The effect of glare is to reduce the contrast which would otherwise be available, and this has to be compensated for by increased field brightness if a given visual response is to be secured and the usual methods of avoidance are not applicable.

Fig. 6 ([19]) indicates the effect of glare in reducing the available contrast at various brightness levels. At first sight, under the condition of the experiment (i.e., producing an intensity of 5 foot-candles at the

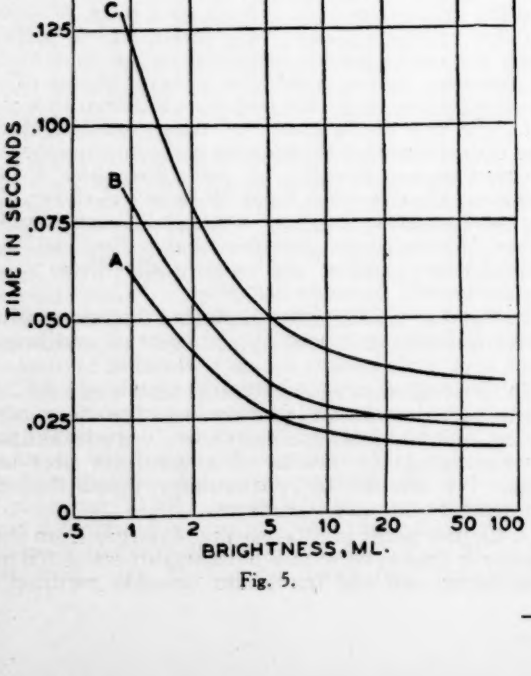

Fig. 5.

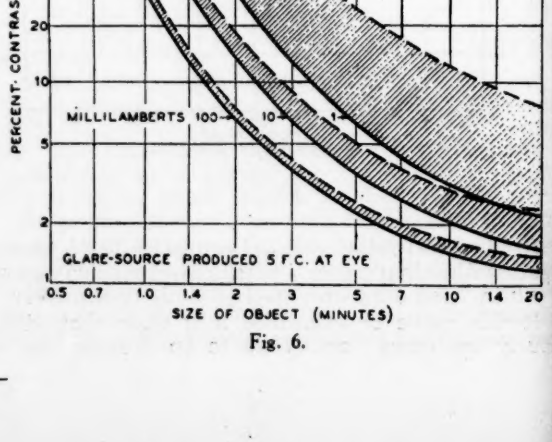

Fig. 6.

eye at an angle of 5° with the line of vision) the effect of glare at brightness levels exceeding 10 millilamberts appears to be small. A more critical examination of the curves, however, somewhat modifies this conclusion.

For instance, at a brightness level of 10 millilamberts, and an object size of 3 minutes, the contrast has to be increased from approximately 6 to 9 per cent. to secure the same visual acuity. From interpolation from Fig. 3 an object size of 3 minutes is visible at a brightness level of about 11-12 millilamberts with a contrast of 6 per cent. With a contrast of 9 per cent., however, an object size of 3 minutes can be resolved at a brightness level of approximately 2 millilamberts.

Under these conditions something like five times the brightness is necessary in order to offset glare. If this is a typical example glare would appear to be somewhat expensive.

Colour.

This is a highly controversial subject. For certain specialised industrial processes monochromatic radiation has useful application, but for the majority of cases sources having spectra similar to that of daylight are to be preferred.

These notes will have made clear the fact that it is difficult to prescribe the brightness level required for the performance of a given visual task from an analytical survey of the factors concerned. We do not know how to combine these factors, and at present cannot, with confidence, compute the result of such a theoretical co-ordination. It would appear, however, that in the great majority of cases there is a desirable mean position between the small advantage to be gained by greatly increasing the brightness level above a given order and economic considerations. It is, of course, admitted that some of the most exacting tasks require high field brightnesses, but from the point of view of economics, and as will be shown from considerations of comfort, these extraordinary tasks should be provided for by local units.

From a practical point of view the recommended values of illumination issued by the Illuminating Engineering Society are a reliable guide to what experience has shown to be desirable, and recognises that very high values are best achieved by supplementing good general illumination by local units.

I.E.S. Code of Recommended Values of Illumination.

For the benefit of those unfamiliar with this code it will be useful to summarise the recommendations.

The values given in the code are average values under service conditions within the area over which the visual task is carried out, which implies that the initial value provided by the engineer above the required service value will depend upon the quality of maintenance prescribed, or to be anticipated.

It is also assumed that no undue variations in illumination level will be experienced over the working plane, and it is recommended that no point of the working area shall be illuminated to less than 70 per cent. of the maximum.

Class.	Recommended ft.-candle value.	Class of Task.
(1)	Above 50	Precision work to a high degree of accuracy. Tasks requiring rapid discrimination, displays, etc.
(2)	25—50	Severe and prolonged visual tasks.
(3)	15—25	Prolonged critical visual tasks.
(4)	8—15	Visual tasks such as detailed office work.
(5)	5—10	Less exacting visual tasks, such as in classrooms and general offices.
(6)	3—5	Work of simple character not involving close attention to detail.
(7)	2—4	Casual observation where no specific work is performed.

Class (1).

I think it will be generally agreed that the areas over which these high values are required in the factory or elsewhere are relatively small, and in consequence better dealt with from all points of view by local units. If this is the case the heat developed by the lighting system would not greatly exceed that associated with a general illumination of from 6-10 ft.-candles.

Class (2).

Although in the I.E.S. Code illumination values of from 15-25 foot-candles are considered adequate for large departmental stores, both for the purpose of close discrimination of detail and for attraction, there is, nevertheless, a tendency to demand higher values.

Recently, before the Decorative Section, an architect stated that values up to as high as 50 foot-candles are demanded in America.

It is of interest to see how comfort conditions are likely to be affected by these values.

As an example, consider a store having a floor area of 10,000 sq. ft. This is a relatively small area for such a store, and there may be three or four such floors in a building of this kind. Assume each floor be 15 ft. high, and the building to be heated by a central heating system. A reasonable heating allowance would be 3-4 B.Th.U.s per cu. ft. Therefore, the heat imput requirements would on this basis, be from 450,000 to 600,000 B.Th.U.s per hour. Let 500-watt metallic filament lamps be adopted, with an average lumen output throughout life of 15 lumens per watt. The utilisation factor will be dependent upon whether the scheme chosen is direct, semi-indirect, or indirect. Making allowance for absorption in glassware, reflectors, etc., let it be assumed that the appropriate factors for the percentage of light reaching an horizontal plane at counter height

is 20, 40, and 60 per cent. respectively, then the figures in the table represent the conditions likely to obtain.

TABLE III.

Illumination level in foot-candles.	% of total heat requirements during lighting hours provided by lighting equipment with "Utilisation factor" of:*		
	20%	40%	60%
15 ...	32	16	11
20 ...	43	22	14
25 ...	54	27	18
30 ...	65	32	22
40 ...	86	43	29
50 ...	108	54	36

* Total heat requirements taken as 525,000 B.Th.U.s per hour

In general (referring to Tables III., IV., and V.) the heating engineer must allow for the total heat requirement of the building, as the lighting load will not be required during the greater part of the period of occupation. If, however, under special circumstances lighting is wanted more or less permanently, economies may be effected by reduction in the capacity of the heating system.

No great precision is claimed for the figures in the above table, but they serve to indicate the order of magnitude of the lighting contribution, and it should occasion no surprise that where the higher values for illumination are superimposed without co-operation from the heating and ventilating engineer very unsatisfactory results are likely to occur.

The following observations appear to be appropriate:

(1) The greater part of the lighting load will probably come into operation just prior to dusk. If it be assumed that the premises were adequately and comfortably heated before the lighting came on, it is apparent, for the higher levels at low utilisation, that comfort conditions will be intolerable.

(2) In the above illustration at levels of from 15 to 25 foot-candles, and with "utilisation factors" of from 0.2 upwards, the lighting load is capable of making a contribution to the heating of the premises, which is of value provided the heating system is thermostatically controlled and flexible enough to make the necessary compensation. With the older type of solid fuel boiler, and especially with installations not fitted with local magnetic or other suitable controls, it will be necessary to anticipate the coming on of the lighting load by adjustments in the boiler room. This is not entirely a satisfactory procedure.

In the author's view the higher values shown in the table are unnecessary, since it is clear that for all but the most exacting visual tasks little visual advantage is to be obtained. It is, however, for the proprietor to determine the prestige value, but these values should not be prescribed without due regard to the economies as well as the requirements of comfort.

Other classes of work for which 25-50 foot-candles are regarded as necessary in the code are typified by:—

(1) Drawing offices.
(2) Extra fine inspection work.
(3) Watchmaking and jewellery.

In regard to (2) and (3) there can be little doubt that these cases are best dealt with by local lighting. It is important, however, that the level of general illumination should be maintained at a reasonable level to avoid fatigue consequent upon frequent adaptation to field brightnesses varying over unduly wide limits.

In the case of drawing offices indirect lighting, where applicable, is sometimes advocated, and there is little doubt that this is effective, since glare effects are eliminated. Indirect lighting, however, implies low utilisation factors, and, in consequence, heat imputs of a higher order than those experienced where more direct methods are applied.

Class (3).

In general, local units are applicable to this range of values.

Class (4) *and* (5).

These classes are of the greatest interest, since they cover a range of from 5 to 15 foot-candles, and the visual requirements for the great majority of tasks may be satisfied by values between these limits.

It is clearly recognised that the heating and ventilating requirements of buildings of similar cubic capacity vary over wide limits, dependent upon the nature of the construction, thickness and area of exposed walls, window space, air change, character of the work to be done, and a variety of other considerations. Moreover, changes in climatic conditions greatly influence the rate of heat loss, and varying thermal capacities, the rate of heating up, etc. In spite of the wide range of variation, it is hoped that two cases may suffice to indicate the order of the contribution the lighting installation can make to the heating requirements. Two systems differing widely in character only are considered, although other systems of heating are, of course, applicable.

Case I.

Consider a single floor factory of area 10,000 sq. ft., with north-light roof and four external brick walls, and let the heating be by means of high-temperature radiant units mounted, say, 10 ft. above floor level. A reasonable requirement, making due allowance for rapid heating up and thermostatic control, under these conditions will be a heat imput from these

panels (say 50 per cent. radiation and 50 per cent. convection) of 6,000 B.Th.U.s per 100 sq. ft. of floor area.

The total B.Th.U. requirement is, therefore, 600,000 B.Th.U.s per hour.

Let the lighting be by:

(a) Gas units fitted with enamelled shades complying with the Home Office recommendations.

From such units, over the floor area specified approximately 140 lumens reach the working plane for each 500 B.Th.U.s heat input.

(b) By 300-watt tungsten lamps fitted in similar reflectors with a reflection coefficient of 70 per cent. The average lumen output throughout life for these lamps is 14 lumens per watt.

In regard to Case I.:

(i) A system of high temperature radiant panel heaters mounted at about 10 ft. above floor level is peculiarly suited to the requirements of this type of building since these structures are usually characterised by considerable heat losses, etc., through the roof, large air change, and cold draughts descending from the upper levels.

In the author's experience commendable comfort conditions may be established if the air temperature is maintained at approximately 50°-55° F., and this is supported by thermal radiation from local sources suitably disposed. This should be equivalent from the comfort point of view to an equivalent temperature of 55°-60° F. Such a system is extremely flexible, and can best be controlled by a eupatheostat (an instrument for maintaining a given equivalent temperature), or very effectively by the usual thermostatic devices.

Care is necessary in the layout of such an installation to secure a fairly even distribution of the thermal radiation, and it is for this reason that heating engineers are now using distribution diagrams similar in all respects to those used by the illuminating engineer.

A distribution diagram of this type for a radiant panel is shown in Fig. 7, and may be compared with that shown in Fig. 8 for a lighting fitting.

The figures in the following table represent the order of the percentage contribution of the lighting load during the period of lighting to the total heat requirements.

TABLE IV.

Illumination level in foot-candles.	% Heat input from lighting installation to total heat requirements during lighting hours.	
	Gas.	Electricity.
5	30	3
8	48	5
10	60	6
15	90	9

The above figures are calculated on the maximum heat requirements of the building.

CASE II.

Consider a factory of floor area 10,000 sq. ft. with four external walls, concrete floors, and ceilings. Height from floor to ceiling 15 ft. Such a case might be considered representative of a three- or four-story mill. Let the building be heated by a central heating

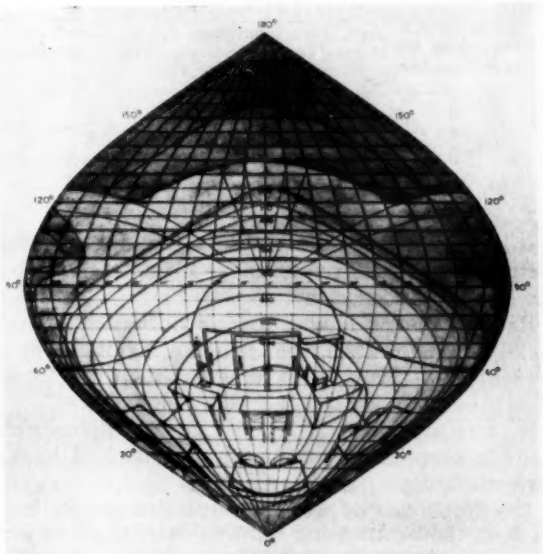

Fig. 7. Typical heat distribution diagram for a high temperature radiant panel showing distribution of radiant flux over a restaurant drawn on the same projection.

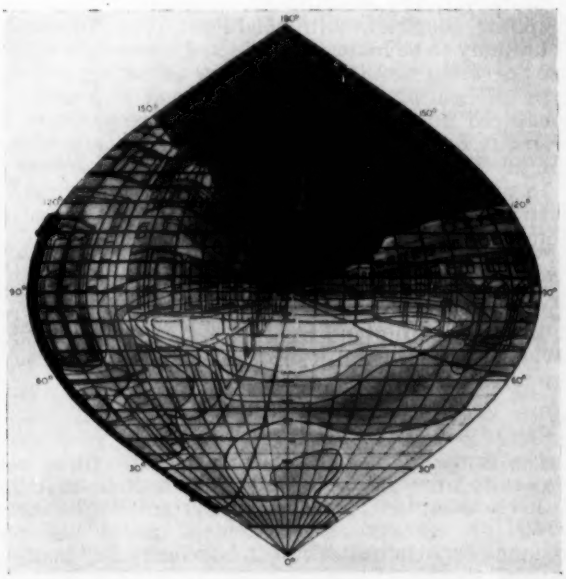

Fig. 8. Typical isocandle diagram of street lighting unit showing the distribution of radiant flux over a street drawn on the same projection.

system, and assume the total heat requirements to be, say, 450,000 B.Th.U.s per floor.

Let similar lighting units be used as for Case I. Then the figures in the table represent the approximate conditions.

TABLE V.

Illumination level in foot-candles.	% Heat input from lighting installation to total heat requirements during lighting hours.	
	Gas.	Electricity.
5	39	4
8	62	7
10	78	8
15	117	12

It is important to note in Case I. that fairly uniform distribution is the requirement in general for both the lighting and heating.

Radiant panels having a total output of approximately 12,000 B.Th.U.s per hour are available at the present time. These units have a radiant heat output of approximately 6,000 B.Th.U.s per hour.

It is clear from Table IV. that gas lighting can make a useful contribution to a controlled heating system employing these panels.

The proportion of heat by convection and radiation for both the heating and lighting units is of the same order, and, in consequence, the desirable proportionality between these two components is not likely to be affected in a measurable degree when the heating system is supported by the heat from the lighting system.

Moreover, the distribution of radiant heat with planning, consistent with good lighting requirements, is unlikely to be materially affected when both agents are operating simultaneously. The advantages of this type of heating are only appreciated if comfort is measured in terms of equivalent temperature or warmth, or due allowance is made over and above the air temperature for the radiation component.

In any case it is desirable to control the heating system in order to accommodate the vagaries of climatic conditions.

In regard to Case II.:

Here again gas lighting can make a useful contribution, but more care needs to be exercised in relating the heating and lighting system at the higher levels of illumination if desirable comfort conditions are to be obtained.

Classes (6) *and* (7).

The range of illuminations covered by these two classes is from 2-5 foot-candles. It is clear that the heat contribution from either system of lighting, whilst in certain cases extremely useful, will not assume proportions difficult to handle by any heating system worthy of consideration In churches and public halls, used intermittently, and where financial considerations make it difficult to put the central heating system in operation early enough to secure comfort, a lighting system contributing substantial radiant heat is advantageous.

General Conclusions in Regard to Illumination Levels.

The ranges of illumination prescribed in the I.E.S. Code are of considerable interest, since, as is to be expected, they interpret the important principle referred to previously that equal increments in illumination do not mean equal increments in seeing facility. On the other hand, equal increments in illumination do correspond to equal increments in the contribution made to the heating by the lighting installation. The same increments in seeing facility will, therefore, represent a much smaller contribution to the heating requirement at the low levels of illumination than at the higher.

Where such high levels are insisted upon the illuminating engineer can assist by choosing units of high utilisation factor. Such a system, however, may place limitations upon the artistic effect it is desired to obtain.

Inferior maintenance at any illumination level is intolerable, but obviously it becomes of greater significance at the higher levels, since, in order to obtain a given minimum performance, it entails higher initial outputs with a correspondingly continuously greater heat input.

The object of this paper will have been achieved if the result is closer co-operation between the heating and lighting engineer.

In conclusion, the author desires to thank the Governor and Board of Directors of the Gas Light and Coke Company for permission to publish this paper, and to acknowledge the co-operation and many helpful suggestions which he has received from his colleagues, Messrs. L. W. Andrew and K. F. Sawyer.

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DISCUSSION

Mr. W. Nobbs (Senior Past-President, Institution of Heating and Ventilating Engineers), who opened the discussion, first apologised for the absence of the President of the Institution, who was in the South of France recuperating.

Referring to the early part of the paper where it was stated that improper heating and inadequate and badly arranged ventilation was detrimental to health, he suggested that the author, in fairness to heating and ventilating engineers, should also have included bad lighting as being detrimental to health!

Commenting on the many references in the paper to experiments that had been carried out in regard to comfort and formulæ that had been devised, Mr. Nobbs said a word of warning was necessary as to the interpretation of such results which must be related to the actual conditions being dealt with from time to time. For instance, the author quoted the factors arrived at by the Royal College of Physicians that in the case of a sedentary individual the heat produced by the body was an average of 400 B.Th.U., and that the loss in a temperature of 60 deg. F., was approximately 45 per cent. by radiation, 31 per cent by convection, and 24 per cent. by evaporation of moisture from the lungs and skin. There were conditions, however, say in a cinema or theatre, where people were closely packed, when these proportionate losses would not apply. The loss of radiation would probably be very much smaller and the other losses would go up.

After agreeing with the author that "comfort" was an extremely difficult thing to define, Mr. Nobbs indicated that he would arrange the author's factors indicating comfort and rate of heat interchange in a rather different order of importance from that adopted in the paper. He then passed to the formula developed by Dr. Bedford, which he characterised as a horrible looking thing, and said he could hardly imagine a ventilating engineer taking the necessary measurements to comply with this formula and then handing them over to a member of his staff to work the whole thing out in order to get an idea of whether the room would be just warm or too warm or only comfortable.

Continuing, Mr. Nobbs did not agree with the author that "comfort is independent of humidity," and pointed out that most experiments on comfort conditions applied to people who were not closely packed. He also said he would have liked an interpretation of the Table giving minimum values of outdoor air requirements, and also commented on the fact that heating and ventilating engineers always spoke of cubic feet per hour, whereas this Table was prepared in terms of cubic feet per minute, which was getting down to very fine figures. This Table also indicated that children in poorer class schools were less clean than those in better class schools, but he did not think there was a great deal of difference nowadays. Again, the conclusion of Dr. Chaumont that as long as the CO_2 due to respiration did not exceed 12 parts per 10,000 the air of the room seemed fresh, was a bogey which had been killed by Sir Leonard Hill years ago, and Sir Leonard had shown that very much higher concentrations caused no deleterious effects.

Commenting on the illumination side of the paper. Mr. Nobbs expressed the view that notwithstanding the great progress that had been made in recent years, the glare problem had not been solved. When we were content to use candles, there were fewer people wearing glasses, and he felt that glare was responsible to a large extent for so many people having to wear glasses to-day.

Mr. A. F. Dufton asked what exactly the author meant by "comfort conditions"? It was stated in the paper, "If it be assumed that the premises were adequately and comfortably heated before the lighting came on, it is apparent for the higher levels at low utilisation that comfort conditions will be intolerable." It seemed that the author used the word "comfort" in a Pickwickian sense, and that, to him, it meant something technical. To most people, however, comfort conditions were never intolerable. With regard to equivalent warmth, when Dr. Bed-

ford published his report on "The Warmth Factor in Comfort at Work," a scale of equivalent warmth had already been proposed in terms of still semi-saturated air, and Dr. Bedford, in publishing his nomogram, recognised the objections to the use of the standard of complete saturation. Equivalent temperature was, of course, intended to be identical with equivalent warmth for the conditions in which humidity effects could be neglected, and it would be unfortunate if the two scales were to differ in practice by two or three degrees because of the reference to the unusual condition of complete saturation. The definition in terms of semi-saturation had now been approved by the Inter-Departmental Committee of the Medical Research Council and the Department of Scientific and Industrial Research.

The contribution of lighting units to the heating of a room, continued Mr. Dufton, was a commonplace, and he mentioned the case of a technical school in which the installation of electric lighting instead of gas rendered the heating system inadequate.

On the question of glare he expressed the view, from experiments made in his own home, that the economy to be secured by uniformity of lighting was not yet fully appreciated.

Commenting on the remark by the president that when he was at school he was taught "light" but not "lighting," Mr. Dufton pointed out that Rumford, 130 years ago, understood the principles of the art of illumination, as would be seen from his essay on "Of the Management of Light in Illumination." Mr. Dufton quoted the following from this essay:—

"It is a well-known fact that a book may be read at night by the light of the full moon, when the air is very clear; and everybody knows that it can be read when illuminated by the direct rays of a bright meridian sun. The differences of the intensities of the light in these two cases is truly astonishing; the intensity of the light of the sun is to that of the full moon, at the surface of the earth, as three hundred thousand to one.

"But, notwithstanding this astonishing power of accommodation possessed by the organ of sight, yet, when the eye passes suddenly from a strong light to one much more feeble, and *vice versa*, nothing can be distinctly seen for some moments. It is true that the eye soon recovers from these momentary derangements, and that habit has rendered them so familiar to us that we seldom take any notice of them; but it is, nevertheless, most certain that they not only injure the eye very much, and weaken it in such a manner as to impair its faculties at a very early period of life, but that they also render it impossible to see surrounding objects so distinctly as they might be perceived, *even with much less light*, were the illumination established on better principles."

Mr. T. C. ANGUS said that Mr. Dufton's reference to the value of uniformity of illumination reminded him of a test carried out in a large business house in the City. In this instance it was found that at the top of some of the ledgers there was an illumination of some 7 foot-candles, whilst at the bottom of the page the illumination was only 1 foot-candle. That meant a great change of adaptation of the eye or some continued change of retinal sensitivity and size of the iris every time the clerk ran his eye down a column of figures, which must entail a considerable nervous strain if continued over long periods.

Speaking both as an illuminating engineer and a heating and ventilating engineer, he remarked that complete agreement as to the physical conditions most desirable to maintain in heating and ventilation had not yet been reached. In America, for instance, with the great variations of the moisture content of the air that occurred in some parts, the effective temperature scale was adopted, but in this country, where, generally speaking, the humidity variations in buildings were of a lesser extent and importance, the employment of other standards seemed to be indicated. In this respect, the illuminating engineers appeared to be much more of one mind than the heating and ventilating engineers. There was no very great divergence of opinion as to what constituted desirable standards of illumination for similar visual tasks, though there were different views as to the merits of different types of lamps. However, from the point of view of illumination, what would be accepted on one side of the Atlantic would probably be equally acceptable on the other side.

In definition of the difficult term "comfort," Mr. Angus said he could not help thinking that where ventilation and warming were concerned, "unconsciousness" was almost synonymous. Setting aside the immediate sensations experienced on entering or leaving a building, the conditions of thermal comfort might well be considered to be satisfactory if the occupants could give their entire attention to other things without the interference of objective sensations. However, it may be open to question whether conditions that may satisfy the requirements of comfort be necessarily ideal for healthy living. Perhaps here again the two physiological requirements of warming and lighting differed, because people seemed to submit to far worse conditions of lighting in workplaces than they would to conditions of too much heat or excessive draughtiness—if it is not altogether preposterous to compare two such things. Dr. Bedford's "comfort zone" was defined as where 70 per cent. of the subjects felt "quite comfortable," and there 86 per cent. fell within the groups of "comfortably warm" or "comfortably cool." Perhaps it might not be impossible to devise some such method of estimating sensations of the effects of lighting.

When considering the experiments of Fishenden and Wilgress on the amount of radiant heat needed to offset cool air, Houghton and McDermott ("Heating, Piping, and Air Conditioning," January, 1935, p. 53) published the results of experiments, showing how much the air had to be warmed to offset the effects of cold walls—an important consideration in a country where nearly all the warmth was supplied to buildings by convection.

Finally, Mr. Angus said that what seems to be most needed now for the guidance of illuminating

engineers is an instrumental method for the measurement of glare.

Mr. P. R. G. OAKS, on referring to the use made of the lighting to add to the heat of a room, suggested to the author that in the case of gas lighting it was the upper air rather than the lower air that was heated. To be effective from the ventilation point of view the air should be heated at or near floor level and extracted at high level. Electric lighting seemed to be better than gas from the point of view that there was less heating and the air was not dried. It seemed to him that the general effect of gas lighting might be to dry the air excessively without adding any real degree of warmth where it is required for the reason above stated. He was inclined to think that better results would be secured by treating the heating and the lighting as separate problems, to be dealt with independently by the experts concerned —the heating expert noting the type and position of lighting units in considering the form of heating and ventilating to be adopted.

Mr. W. GILCHRIST remarked that if lighting engineers could design fittings which gave off no heat, the problem of the heating and ventilating engineer would be simply to arrange for a temperate temperature. Mr. Smith appeared to be more interested in radiation than convection, but all the new apparatus now being produced showed a tendency towards convection owing to the desire for comfort conditions. In the case of a large store building which required artificial light all day, with an area of 250,000 cub. ft., the increase in the temperature due to lighting was of the order of 5 per cent., and this was a very important factor in the heating calculations. He had a building under review at the moment in which, should fluorescent tube lighting be adopted. the normal heating requirements would have to be considerably increased, and coke or coal would have to be used which otherwise would not be necessary. Whilst not wishing to enter into controversial aspects he thought that if gas lighting were used very much more air change was required than if the lighting was electric.

In referring to air change, Mr. Gilchrist commented upon the Table in the paper giving minimum values of outdoor air requirements. He remarked that if one took an average classroom of 24 ft. by 24 ft. by 11 ft., and worked on the cube of that, twelve changes of air per hour were necessary whereas the Board of Education regulation required three air changes per hour with natural ventilation. Continuing, Mr. Gilchrist said the difficult calculations which had been mentioned were very seriously offset when one got down to brass tacks and found out what was being done in the heating world to-day. In the case of schools, for instance, it was common to find that with the usual spacing of desks of 2 ft. for children of from six to fourteen years, one child would be subject to the equivalent heat from 40 sq. ft. of radiator radiating 160 B.Th.U., and the next child would be subject to the draft from an east wind coming from a window immediately above the child. The obvious answer was that comfort conditions could only be obtained by a combinaton of low temperature radiant heating and air conditioning.

With regard to lighting, he said it was important to arrange the lighting fittings in relation to the ventilation so as to ensure that the proportion of the air at the higher temperature near the ceiling could be brought down to the average level, and thus keep a more even mean temperature throughout the room.

Mr. H. LINGARD said he did not know whether the author was speaking as a heating and ventilating engineer or as a lighting engineer, or both—but if he was speaking as an illuminating engineer, then he was to be admired for his courage in confessing to heating and ventilating engineers some of the inefficiences of our lighting systems. From that point of view it seemed that the lighting engineer could do 90 per cent. of the heating engineer's job! Nevertheless, the position was not quite as bad as that because as lighting levels tended to increase, the total amount of heat given off tended to decrease for the same degree of illumination. The fact should not be overlooked that light sources became colder as development proceeded. If one looked at the old carbon lamp and took the heat emission from that as 100, the figure for the vacuum lamp was 40, for the gas-filled lamp 23, and for the modern discharge lamp only 6.

Mr. A. CUNNINGTON, commenting on the reference in the paper to the reaction of the public in these matters of lighting, heating, and ventilation, said that from experience he was inclined to think that as regards 90 per cent. the reaction was generally a grumble, and in the case of the other 10 per cent. there was likely to be mildly expressed satisfaction. That seemed to him about the best that could be hoped for in the way of reaction to the efforts of lighting and heating engineers. In reading the paper he felt envious of the instruments which heating and ventilating engineers had, and the manner in which they were able to make precise measurements, for on the lighting side they had not quite the same array of instruments.

Moreover the heating engineers had the advantage of a fairly close agreement as to what were comfort conditions in respect of heating and ventilation. No one would be rash enough to suggest that a temperature of 600° F. would be pleasant for room heating when they knew that 60° F. was adequate. Yet in the lighting field, although 12 ft.-candles might be ample illumination for ordinary use there were plenty of people ready to encourage illumination values of 120 ft.-candles. What a pity there was no automatic check on excessive illumination similar to the extreme discomfort experienced in a greatly over-heated room!

One of the most interesting parts of the paper to him was the discussion of the effect of lighting upon the heating of a room or building. which had been mentioned previously before the Society. He himself had pointed out that it was rather fortunate on the whole that artificial lighting was of the greatest importance in the winter season, when it might also

be of some use from the heating point of view. There was, however, great necessity for control of the heating if advantage was to be taken of the heat from the lighting installations, but there should be no difficulty in that with the thermostatic control now available. He enquired if there were any figures available of the heat effect of the lighting in buildings which were permanently lighted artificially. The premises of the Lighting Service Bureau were a very good example of that. He wondered if Mr. Lingard, in the absence of Mr. Jones, the manager of the Bureau, could give any information in that connection, and whether any allowance was made for the lighting when the heating requirements were dealt with.

Dr. E. H. T. NASH remarked that as representing school medical officers he had been concerned to hear a previous speaker suggest air-conditioning for schools. He sincerely hoped it would never happen in his lifetime. The constant struggle at the present time was to get people to open their windows and let the air in, but if we were to go to sealed windows and conditioned air systems we should put the clock of progress back for years. There must be something radically wrong in a heating system which permitted such extremes of temperature as a previous speaker had mentioned. Speaking generally on the question of ventilation by natural means, Dr. Nash recalled an investigation some years ago of the conditions in back-to-back houses which led to the conclusion that if these houses had a 14-in. square chimney they were entirely satisfactory from the health point of view due to the perflation across the chimney top.

Mr. H. H. BRUCE said the remark in the paper that humidity had only a secondary effect on comfort required a good deal of qualification, because there were circumstances in which humidity and air movement became of infinite importance.

Mr. G. H. WILSON said it seemed to him that Mr. Smith's conclusions in Tables IV. and V. were winter conclusions and not summer conclusions. It was pointed out in the paper that the lighting could make a useful contribution to the heating system. It did seem to him, however, that if the lighting could supply 90 per cent. of the heat required in the winter, then the figure would have to be measured in terms of discomfort in the summer and not in terms of the percentage of the total heat required. If the lighting was only used in the summer, then Mr. Smith's conclusion was sound, but where night-shifts were being worked in the summer then it would be necessary to measure discomfort and not the value from the point of view of the heating effect obtained from the lighting. This rather strengthened his own conviction that the ideal was to get the minimum amount of heating from the lighting, where possible.

Mr. J. COTTERILL, speaking with regard to equivalent warmth, referred to the value of 61° F., given in the paper. He asked the author to state the source of the information on which that was based, and also the basis of the temperature scale of 62° to 69° F.

Mr. PERCY J. WALDRAM (communicated) desired to contribute to the discussion on this original and valuable paper a suggestion which would undoubtedly be unorthodox and might be considered heretical.

It had been impressed upon him recently by the coincidence of hearing within the space of a very few days three somewhat remarkable pieces of evidence with regard to illumination and ventilation which, when co-ordinated, give food for thought if not concern.

The first was a statement by a physician of world-wide reputation to the effect that workers in conditioned air developed consistent afternoon lowering of vitality and drowsiness to an extent which had reached in America the proportions of a serious social question.

The second was a statement by the managing director of a well-known establishment where specially skilled saleswomen retailed expensive goods—pictures, prints, and articles of high artistic merit and the like, which required the best possible illumination. Some of the sale rooms had good natural light; in others, where only artificial light was possible, the illumination was the best which could be obtained—well-designed and ample in amount.

He was informed that the longest period under which typical saleswomen could work all day and every day under artificial light without developing eye trouble necessitating absence and ophthalmic treatment was about three or four weeks in a department artificially lit.

The third was the experience of an engineer responsible for the lighting of a very large number of offices. He stated that amongst gamekeepers and poachers whom he had known in Scotland from boyhood it was customary to find elderly men whose eyes were puckered up by the habitual strain of peering into dark coverts and undergrowths, but whose eyesight was, nevertheless, far superior to that of sedentary workers accustomed to clerical work under ample and steady artificial light.

In view of the enormous variations in the intensity of daylight from hour to hour and often from minute to minute, and the similar variations in the velocity and temperature of air currents out of doors, the disquieting conclusion was forced upon him that possibly the steady perfection for which one strove so assiduously in conditioned air and in artificial illumination might, perhaps, be, by its monotonous excellence, its greatest evil.

Possibly the human eye, like the human skin, cannot function properly without the exercise of the reactions which are called for by the variations of natural light and air.

The proper use of artificial light and artificial ventilation is, of course, to make good the deficiencies of Nature to meet the pace and conditions of modern life, which requires industrial operations to be carried on continuously indoors irrespective of weather

and beyond the daily hours over which adequate natural illumination is available.

If one tried to extend what were really means for mitigating conditions which are forced upon one into an endeavour to supplant Nature by means of windowless factories and conditioned air, one might be running a serious risk.

The unanimous prejudice against working all day and every day under artificial light and artificial ventilation, however excellent, might be exaggerated unconsciously by lack of experience of good artificial lighting and ventilation: or it might not. But factories, once built, had a way of persisting for long periods, twenty, fifty, or one hundred years, during which an enormous total number of working hours were spent in them.

Unless therefore, irrefutable clinical evidence was available to prove that the popular prejudice was a popular fallacy, there was everything to be said for utilising to the full such natural light and air as was left in our overbuilt towns.

Mr. F. C. SMITH, replying to the discussion, agreed with Mr. Nobbs that caution was necessary in applying the work that had been done on comfort conditions, and also in interpreting the results obtained, but surely this was a necessary precaution in all technical work. He quite agreed that the conditions in a crowded cinema or theatre were peculiar, and affected the manner in which the body loses heat, but, after all, this did not alter the fact that for ideal conditions the body should lose heat by radiation, convection, and evaporation in given proportions. The aim should, in his, the author's, opinion, be to arrange the heating to achieve ideal results as far as circumstances will permit. The heating system should be flexible enough to allow of the necessary compensations being effected. These compensations should be applied as far as possible automatically.

He also agreed with Mr. Nobbs that the order of importance to be attached to the various factors affecting heat loss was not in all cases the same as the order given in the paper. With regard to CO_2 concentration, he would be the last person to suggest that 2-parts in 10,000 was in any way harmful, especially if it were remembered that seaside air contains something like 3½-parts per 10,000. As a matter of fact, a concentration of 2 per cent., if not to be advocated since it would probably be an indication of insufficient air change, was permissible.

Mr. Smith thanked Mr. Dufton for clearing up a little misunderstanding with regard to equivalent temperature and equivalent warmth, the point had been covered in the original paper, but it had been omitted since, perhaps, he had not fully realised its true significance. Mr. Dufton has also spoken of the need of uniform illumination.

Mr. Smith, referring to the Code of Illumination values published by the Illuminating Engineering Society, indicated that this Code suggested that the minimum illumination on the working plane should not be less than 70 per cent. of the maximum value on this plane.

Commenting upon the remarks of Mr. Angus, with special reference to the case mentioned of a variation from 1 f.c. to 7 f.c. on a ledger, Mr. Smith stated that 1 f.c. was far too low an illumination for ledger work, and he agreed that diversities of the kind mentioned by Mr. Angus should not occur at these levels of illumination. He further agreed with Mr. Angus that conditions in regard to heating which were suitable in America were not of necessity those to promote comfort conditions here.

On the question of effective temperature, he said that he had summarised the information in regard to this, and perhaps for that reason the statement was not so clear as it might otherwise have been.

Mr. Oaks had suggested that gas lighting only heated the upper air in a room, but he felt that Mr. Oaks had entirely neglected the radiant component from such an installation and the valuable contribution this made to comfort conditions. In the diagrams given in the paper, the distribution of radiant heat in the lower hemisphere was shown for both gas and electricity. Whilst a certain amount of convection occurs from a gas unit the author claims this to be advantageous, since the convection helps to bring about air movement, which had been shown on many occasions to be advantageous. He recalled the case of a piano factory where the very conditions that Mr. Oaks had criticised had been shown as necessary if the work was to be satisfactorily carried out. Moreover, this convected heat did a great deal to prevent cold draughts coming down, which were so disconcerting. Mr. Oaks had expressed the view that it was better to keep the heating and lighting requirements separate, but Mr. Smith maintained that these two requirements were so inter-related that this could not be done. It was impossible for the heating engineer to entirely ignore the contribution from the lighting, especially at high illumination values.

Replying to Mr. Gilchrist on the question of convection, Mr. Smith stated that he had referred in the paper to two widely differing systems of heating, one being a system with a large radiant component, and the other a central heating system in which the main contribution was by convection. He did not agree that convection was the most effective method of heating and he was glad to have the support of Dr. Nash in that respect. There were, however, systems of heating which came between the two cases he had mentioned, which definitely had, under appropriate circumstances, useful application. The whole point was that when prescribing certain illumination levels, heat was produced in quantity related to the illumination level described and, therefore, it was necessary that collaboration should take place between those responsible for the heating and those dealing with the lighting.

Mr. Gilchrist himself emphasised this point in the example he had given of fluorescent tube lighting. He had stated that if a system of lighting was used which gave a great deal of light and little heat then, of

course, the normal heating system was inadequate and must be supplemented. Mr. Smith appreciated that fluorescent tubes were very efficient from the lighting point of view, but he had not mentioned them in the paper because he did not regard them as practical politics from the point of view of the example he had given, i.e., that of store lighting. He was at a loss to know what had prompted Mr. Gilchrist to say that with gas lighting more air change was required; the whole point was that there should be co-operation between the heating and lighting engineers in order to obtain the most efficient results. From a technical point of view, and this view was supported by the conclusions of the Committee appointed by the Royal College of Physicians to which he had referred in the paper, the same order of air change was necessary if healthy conditions were to be established, whether the heating was by an electric radiator or a flueless gas heater.

In regard to the effect of lighting upon comfort conditions in premises continuously lighted by artificial means, and especially where the illumination was of a high order, his experience has been that in many cases comfort conditions left a great deal to be desired. He was very glad, indeed, to hear that Dr. Nash spoke with such emphasis as to the necessity for air change as he agreed with Dr. Nash that adequate air change, as distinct from air movement was essential to health.

In reply to Mr. Wilson, the author said that to take the exceptional case as the basis of a statement made bad law. As a rule lighting was not used in the summer months to the same extent as in the winter. There might be cases such as munition factories and other similar places where work had to continue through the night even in the summer months. In cases of this kind Mr. Wilson's contention was real. In many cases, however, the level of illumination could be lowered without any great harm being done, especially if the level of illumination was on the flat part of the curve for the particular process. In any case, where experimental high levels were in use these would probably be obtained by local lighting and would not occasion difficulty to the same extent as Mr. Wilson had visualised.

He recalled that the Departmental Committee set up by the Ministry of Transport had regarded fog conditions as abnormal and were not prepared to legislate for conditions which it was deemed were exceptional.

Replying to Mr. Cottrill, Mr. Smith stated that his authority for quoting 61° equivalent warmth as the best condition for comfort under sedentary conditions was the statement made in the paper by Bedford, under reference 7, in the bibliography given in the paper.

Commenting upon Mr. Waldram's written contribution, Mr. Smith said that he had no evidence to support or refute the statement that conditioned air developed consistent afternoon lowering of vitality, but in his view air change brought about by sufficient natural ventilation was always to be preferred provided the air admitted by such a system was clean and pure. He certainly would join with Mr. Waldram in suggesting that as much natural daylight as possible should always be available in our buildings.

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